AN SOLR CALIBRATION FOR ACCURATE MEASUREMENT OF ORTHOGONAL ON-WAFER DUTS

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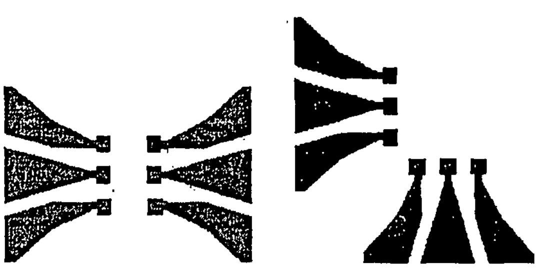
ABSTRACT

Orthogonal CPW thrus are notorious for generating undesired modes due to the bend discontinuity. These undesired modes are not accounted for in conventional calibration methods such as SOLT, LRM, and TRL, since they require, by definition, well-behaved thru standards. In this paper, we will demonstrate through experimental results how the Short-Open-Load-Reciprocal thru (SOLR) approach, which avoids imposing any dependency on the nature of the thru standard itself, provides a superior calibration.

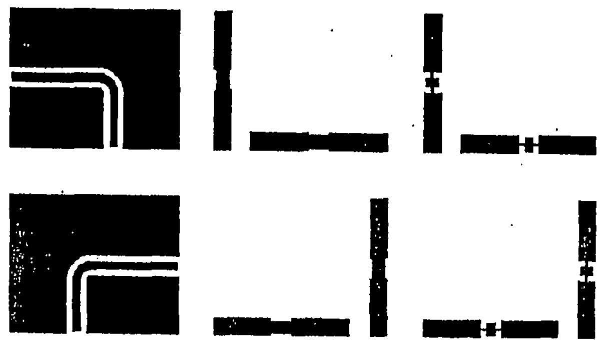
INTRODUCTION

Conventional calibration methods such as short-open-load-thru (SOLT), line-reflect-match (LRM), and thru-reflect-line (TRL) require that the thru standard be well behaved. This allows it to be modeled as a 50 Ω line with a specific loss and delay characteristic [1, 2]. This condition is relatively easy to satisfy for standard DUTs with East-West ports. The thru is typically made electrically small (about 1ps delay) so that it represents a near lossless, CPW-mode 50 Ω line. In orthogonal DUTs, however, a



(a) (b)

Figure 1. Straight across (a) and orthogonal (b) microwave wafer probing.



thru short load

Figure 2. CAD layout of the orthogonal ISS including orthogonal CPW thru standard. The 50 ohm cross-sectional impedance is maintained by the continuous bend.

'nice' CPW thru becomes difficult to fabricate (Figure 1). The thru is not only considerably long but has a right-angle bend in it (Figure 2). The bend discontinuity, regardless of how carefully it is mitered, gives rise to a slot-line mode, and in a lesser extent to leaky parallel-plate and surface wave modes [3, 4]. We will show how these undesired modes distort the ideal CPW-mode behavior of the line and introduce a large error into a conventional calibration, but is remedied by the SOLR approach.

One approach to orthogonal probing may be to use a straight across calibration and carefully reorient the probe prior to measurement. This additional step is inconvenient and may introduce errors due to changes in electrical behavior when the cable and probe are repositioned. If this step is performed carefully using high quality phase-stable cables, however, it is possible to obtain good results.

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SOLR CALIBRATION

A variation of the SOLT calibration, the SOLR – Short-Open-Load-Reciprocal first described in [5] – does not require a known thru standard. As the name suggests the only assumption for this standard is that it is reciprocal with $S_{12} = S_{21}$ for equal impedance ports.

In the SOLT, LRM, and TRL calibrations the thru standard is defined as

$$S = \begin{bmatrix} 0 & e^{-\gamma \cdot l} \\ e^{-\gamma \cdot l} & 0 \end{bmatrix} \quad (1)$$

where γ and l denote the propagation and length of the transmission line standard.

In particular, SOLT uses the thru to calculate the port match and transmission terms based on a three-measurement port system. The need for a known thru definition is eliminated in SOLR by using the switching terms of a four-measurement port system to calculate the load match error coefficients. This 8-term error model for SOLR is the same as in the TRL and LRM family of calibration algorithms [1] and is shown in Figure 3.

This error model has eight unknowns although only seven must be fully determined to complete the calibration (since S-parameters are ratios). The error box terms S_{11}, S_{22}, and $S_{12} \cdot S_{21}$ are determined from the one-port Short-Open-Load (SOL) standard measurements, essentially equivalent to the SOLT approach. Hence, in an actual one-port measurement the results for SOLT and SOLR should be identical. The relationships between the S_{12} and S_{21} terms must be determined from the reciprocal standard.

When the DUT is replaced by the reciprocal standard the measured overall S-parameters are given by the signal flow graph. The forward and reverse transmission measurements are then:

$$S_{21,m} = S_{21,a} \cdot S_{21,r} \cdot S_{21,b} \,/\, denom \quad (2a)$$

$$S_{12,m} = S_{12,a} \cdot S_{12,r} \cdot S_{12,b} \,/\, denom \quad (2b)$$

where the m, a, b, and r denote *m*easured, error box a, error box b, and *r*eciprocal standard, respectively. The denominator is the same for both measurements and consists of the second-order loop terms for the flow diagram and can be calculated.

The ratio of the measured transmission terms then gives an equation involving only the S_{12} and S_{21} terms of the error boxes:

$$\frac{S_{21,m}}{S_{12,m}} = \frac{S_{21,a} \cdot S_{21,b}}{S_{12,a} \cdot S_{12,b}}. \quad (3)$$

This term, when combined with the products obtained from the two short-open-load one-port calibrations, provides enough information to complete the two-port calibration. This derivation shows that the definition of the thru is not required for the calculation of the error box terms. This characteristic of the SOLR calibration approach is powerful in probe card applications and for orthogonal DUTs. In these cases the ports may be physically distant or may require angled thru connections.

The SOLR algorithm is not available on any commercial VNA and requires external processing and software such as is available in WinCal™ [6]. While calibration is completed externally, the error coefficients are downloaded to the VNA allowing fully calibrated measurements without further intervention.

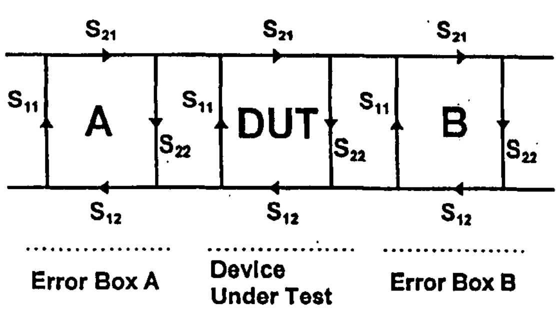

Figure 3. The signal flow diagram of the switch corrected error model.

MEASUREMENTS

A number of calibrations were made to compare the performance of the different methods. Probe placement errors were reduced by precise positioning using a Cascade Microtech Summit 10101 semi-automatic probe station. After the open, short, load, and thru measurements were made we computed (using WinCal) SOLR, SOLT, and LRRM error coefficients based on the same data. This allows direct comparison of calibration methods and avoids the distractions of minor measurement variations and noise. Each calibration was downloaded to the HP 8510 VNA using WinCal and various S-parameters were measured.

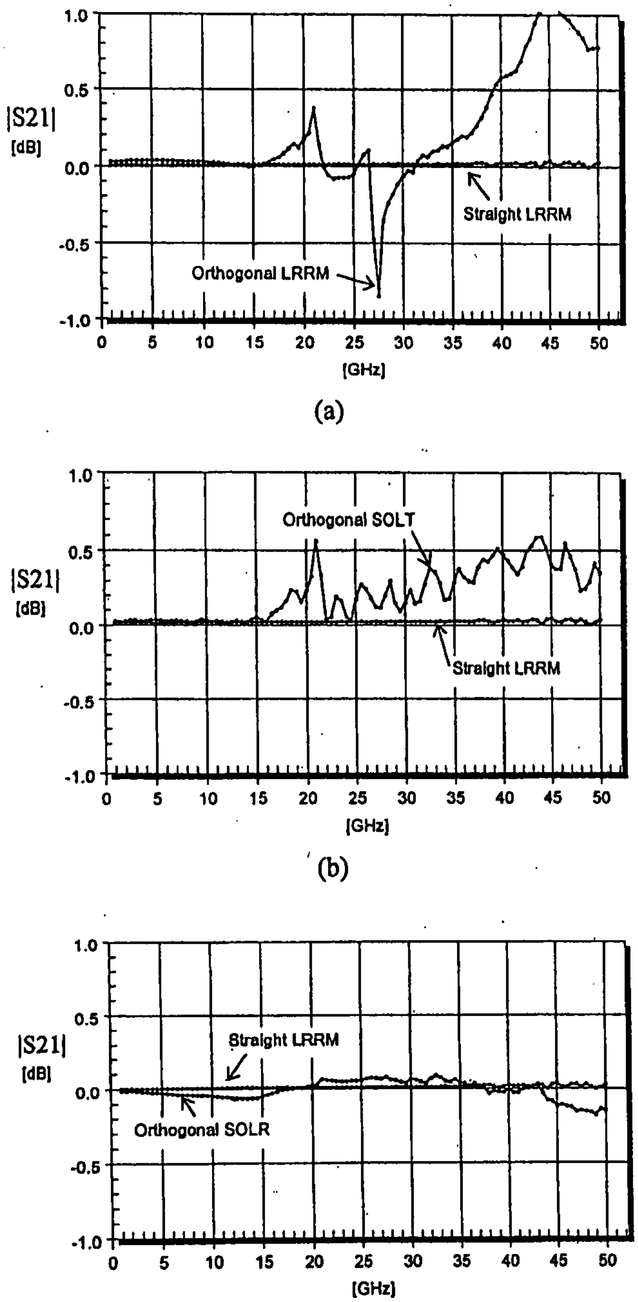

Figure 6. Insertion loss measurements of a straight 1 ps CPW thru standard using reference straight-across LRRM and orthogonal (a) LRRM, (b) SOLT, and (c) SOLR calibrations.

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